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Greater Healthful Dietary Variety Is Associated with Greater 2-Year Changes in Weight and Adiposity in the Preventing Overweight Using Novel Dietary Strategies (POUNDS Lost) Trial[1–3]

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Abstract

Background: Greater healthful dietary variety has been inversely associated with body adiposity cross-sectionally; however, it remains unknown whether it can improve long-term weight loss.

Objective: This study prospectively examined associations between healthful dietary variety and short-term (6 mo) and long-term (2 y) changes in adiposity in the Preventing Overweight Using Novel Dietary Strategies (POUNDS Lost) weight-loss trial completed in 2007.

Methods: Healthful dietary variety was assessed from 24-h recalls with the use of the US Healthy Food Diversity index among participants aged 30–70 y with overweight/obesity (n = 367). Changes in the index between baseline and 6 mo were divided into tertiles representing reduced (T1), stable (T2), or increased variety (T3). Body weight and waist circumference (WC) were measured every 6 mo, and the percentage of body fat and trunk fat were measured at 6 mo and 2 y. Associations between changes in variety and short-term and long-term changes in adiposity were analyzed by use of multivariable-adjusted generalized linear models and repeated-measures ANOVA.

Results: Regardless of dietary arm, T3 compared with T2 was associated with greater reduction in weight (−8.6 compared with −6.7 kg), WC (−9.1 compared with −6.1 cm), and body fat at 6 mo (β = −4.61 kg, $P < 0.05$). At 2 y, individuals in T3 compared with those in T2 or T1 maintained greater weight loss [−4.0 (T3) compared with −1.8 kg (T2 and T1), $P = 0.02$] and WC reduction [−5.4 (T3) compared with −3.0 (T2) and −2.9 cm (T1), $P = 0.01$]. Total body fat and trunk fat reductions were similarly greater in T3 than in T2.

Conclusions: Increasing healthful food variety in energy-restricted diets may improve sustained reductions in weight and adiposity among adults with overweight or obesity on weight-loss regimens. This trial is registered at clinicaltrials.gov as NCT00072995. *J Nutr* 2016;146:1552–9.

Keywords: POUNDS Lost, dietary variety/dietary diversity, healthy food diversity, weight loss, weight maintenance, obesity

Introduction

Sustained weight loss is difficult to achieve. In the United States, adults who successfully lose weight regain more than half of that weight after 2 y (1–3). Biobehavioral, psychological, and environmental factors may influence weight regain (4, 5), partly because weight loss and weight maintenance are inherently different processes that each respond to different stimuli (6). For example, clinically meaningful weight loss can be achieved by most healthy adults by simply reducing energy intake and increasing energy expenditure, leading to immediate perceived and tangible benefits that outweigh the effort (6). However, weight maintenance becomes harder when the initial reinforcing factors disappear, and the costs associated with ongoing deprivation, including dietary monotony and hunger, exceed the benefits (7). Additionally, highly accessible, palatable, energy-dense foods contribute to excess energy intake (8), which further hinders maintenance.

Given the barriers to sustaining weight loss, novel and sustainable approaches are needed to enhance long-term weight

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maintenance. Combating dietary monotony and hunger by increasing variety with healthful, low-energy dense foods may be a rewarding area to explore given the hurdles in the current food environment that challenge weight maintenance (9). In clinical and epidemiologic studies, increasing food variety has been consistently associated with increased intake (10–12), suggesting that dietary variety applied exclusively toward healthful foods could increase intake of these foods and improve diet quality. Greater healthful food variety increases people's exposure to new flavors, which may increase their appetite for these foods and help them lose and sustain weight loss. Greater variety within low energy-dense foods like fruits and vegetables can increase intake of these foods and potentially displace intake of less healthful foods by simultaneously combating monotony and promoting satiety (12, 13).

Previously, we developed and validated the novel US Healthy Food Diversity index to measure healthy food variety by concurrently examining the number of unique foods consumed, the proportion of each food in the diet, and the healthfulness or quality of each food (14). Thus, the index assesses total dietary variety but only allocates favorable variety scores to individuals who consume a variety of food groups recommended in the 2010 Dietary Guidelines for Americans in appropriate portions (i.e., healthful variety). In cross-sectional studies, we showed that this healthful variety index was associated with lower BMI, waist circumference (WC)[8], body fat, and some metabolic parameters (15, 16). However, it remains unknown whether greater healthful food variety supports weight loss and weight maintenance. Therefore, the objective of this study was to investigate the longitudinal associations between healthful dietary variety and short- and long-term weight loss and maintenance and adiposity among participants on energy-restricted diets in a 2-y clinical weight-loss trial.

Methods

Study population and measures. The Preventing Overweight Using Novel Dietary Strategies (POUNDS Lost) trial was a 2-y multicenter randomized controlled clinical weight-loss trial completed in 2007. The trial is registered at clinicaltrials.gov as NCT00072995. Detailed information about the trial design has been previously published (17). By use of a 2-by-2 factorial design, the study enrolled and randomly assigned 811 adults aged 30–70 y and with a BMI (in kg/m^2) of 25–40 to 1 of 4 diet arms: low-fat (20% from total energy) and average-protein (15%); low-fat and high-protein (25%); high-fat (40%) and average-protein; and high-fat and high-protein. Carbohydrate prescriptions ranged from 35% to 65% of energy to test for a dose-response effect. The present study includes participants from a 50% sample (n = 367) randomly selected to provide detailed 3-d dietary recalls at 6 mo and 2 y (18). At baseline, participants had high levels of weight-loss motivation as assessed via interview and questionnaire, were free of diabetes and unstable cardiovascular disease, and did not use medications that could influence body weight. Each participant's resting energy expenditure and activity level were measured and used to prescribe an energy deficit of 750 kcal/d to lose ~1.5 pounds (0.68 kg)/wk. The trial was approved by the human subjects committees at the Harvard T.H. Chan School of Public Health and Brigham and Women's Hospital and the Pennington Biomedical Research Center and by a data safety monitoring board appointed by the National Heart, Lung, and Blood Institute. All participants provided written informed consent.

[8] Abbreviations used: POUNDS Lost, Preventing Overweight Using Novel Dietary Strategies; T1, tertile 1, reduced dietary variety; T2, tertile 2, stable dietary variety; T3, tertile 3, increased dietary variety; WC, waist circumference.

Exposure definition. Participants kept detailed 5-d food records at baseline to ensure intervention compliance with ongoing self-monitoring. These records were used to calculate dietary variety at baseline. From the 367 participants randomly selected to report their diet via 3 nonconsecutive 24-h recalls by use of the USDA Automated Multiple Pass Method (18), 97% completed them at 6 mo, and these 3 recalls were used to calculate dietary variety at 6 mo. Only 186 had dietary recalls at 2 y, and thus variety scores at 2 y were not computed. Baseline food records were analyzed with Moore's Extended Nutrient Database built by use of USDA food composition tables, and dietary recalls were analyzed by use of the USDA nutrient database.

Healthful dietary variety was defined at baseline and 6 mo by use of the US Healthy Food Diversity index, by use of the previously published (15, 16) and validated equation detailed below (14):

$$\text{US Healthy Food Diversity index} = \left(1\text{-}\sum s_i^2\right)\times \text{hv where}$$

$$s_i = \text{share of food item i based on volume in the total diet}$$

$$\text{hv} = \sum \text{hf}_i \times s_i$$

$$\text{hf} = \text{health factors of food}$$

Briefly, the index is computed by disaggregating individual food codes into their relative fraction of 26 food groups and subgroups by merging food codes with the MyPyramid Equivalents Database (19); as the number of unique foods increases, so does dietary variety. Proportionality and dietary quality are incorporated into the index by multiplying and summing individual food shares (s_i), or relative proportion of each food in the diet, by pre-established health factors (hf) derived from the recommended intakes of each food group in the 2000-kcal/d USDA food pattern in the 2010 Dietary Guidelines for Americans. The index has a theoretical range between 0 and nearly 1, with higher scores indicative of diets with greater variety within more heavily weighted (i.e., more healthful) food groups, in the USDA recommended proportions. The change in the US Healthy Food Diversity index from baseline to 6 mo was the exposure variable, and it was computed and examined in 2 ways: continuously as well as categorized into tertiles representing reduced (T1), stable (T2), or increased (T3) variety.

Outcome definition. Body weight was measured by trained study personnel on 2 nonconsecutive days at baseline, 6 mo, and 2 y and on single days at 12 and 18 mo. All participants were weighed in the morning by use of calibrated hospital scales. WC was measured at the same time points with an inelastic tape measure, 4 cm above the iliac crest. A 50% randomly selected sample had their body composition analyzed with DXA by use of a Hologic QDR 4500A bone densitometer, from which total percentage of body fat and percentage of trunk fat (i.e., body fat between the neck and pelvis) were obtained.

Covariates. Sociodemographic and lifestyle characteristics including household income, race/ethnicity, educational attainment, and smoking status were self-reported at baseline. Intervention compliance was assessed by use of both 24-h recalls and FFQs and was computed as the absolute kilocalorie departure from the prescribed energy deficit. We adjusted for the influence of total energy intake on weight by including degree of adherence to the prescribed energy deficit (i.e., energy intake − energy prescribed) using the values reported from repeated 24-h recalls because of their accuracy (20) and relevance for the dietary exposure. Habitual physical activity was assessed by use of the validated 16-item Baecke physical activity questionnaire (21) administered at baseline, 6 mo, 12 mo, and 2 y. Total physical activity was calculated by summing the leisure, sports, and work activity indexes.

Statistical analysis. The change in the US Healthy Food Diversity index from baseline to 6 mo was the exposure variable, which was computed by subtracting US Healthy Food Diversity scores at baseline

TABLE 1 Descriptive characteristics of POUNDS Lost participants with overweight and obesity from a subset with 24-h recall data (n = 231–367)[1]

	Baseline	6 mo	12 mo	2 y
Age, y	52.3 ± 8.9			
Sex, % female	55.6			
Race/ethnicity, % white	84.2			
Education, % ≥college degree	71.7			
Annual household income, % ≥$100,000	34.3			
Smoker, % ever smoker	41.7			
US Healthy Food Diversity Score[2]	0.43 ± 0.06	0.41 ± 0.06*	—	
Physical activity score[3]	6.99 ± 1.39	7.25 ± 1.30	7.33 ± 1.32*	7.08 ± 1.31
Weight, kg	93.8 ± 16.0	86.9 ± 16.0*	87.0 ± 16.2*	89.5 ± 16.4*
Δ Weight,[4] kg		−6.91 ± 5.66	−6.87 ± 7.33	−4.30 ± 7.39*
Waist circumference, cm	105 ± 13.2	97.4 ± 13.1*	96.8 ± 13.6*	99.0 ± 13.7*
Δ Waist circumference,[4] cm		−7.13 ± 6.37	−7.73 ± 7.62	−5.52 ± 8.04*
Total body fat,[4] %	36.9 ± 6.85	34.0 ± 7.72*	—	34.6 ± 7.82*
Δ Body fat,[4] %		−2.97 ± 2.80	—	−2.27 ± 3.40*
Trunk fat,[5] %	37.9 ± 5.92	34.2 ± 7.29*	—	34.9 ± 7.18*
Δ Trunk fat,[4] %		−3.78 ± 3.76	—	−2.99 ± 4.38*

[1] Continuous data are presented as means ± SDs, and categorical data are presented as percentages. Changes in adiposity parameters over 2 y are compared with the initial 6-mo change. *Different from baseline values, $P < 0.05$. POUNDS Lost, Preventing Overweight Using Novel Dietary Strategies.

[2] From the 367 participants with dietary data at baseline, 356 had data at 6 mo. Only 186 had data at 2 y, and thus variety scores at 2 y were not computed.

[3] Habitual physical activity was assessed by use of the validated 16-item Baecke physical activity questionnaire (21), and total physical activity was calculated by summing the leisure, sports, and work activity indexes.

[4] Changes in adiposity parameters are computed as the differences from baseline.

[5] Percentages of body fat and trunk fat were measured by use of DXA.

from the 6-mo values. We then examined our exposure variable in 2 ways: continuously and categorized into T1, T2, or T3. We examined associations between initial 6-mo changes in dietary variety and short-term (6-mo) and long-term (2-y) changes in body weight and adiposity (continuous outcomes). By use of generalized linear models, we examined the association between tertiles of change in variety score and change in body weight, WC, percentage of trunk fat, and percentage of body fat at 6 mo (6-mo measure − baseline measure). Initial models were adjusted for age, sex, and diet arm, and multivariable models were further adjusted for smoking status, race/ethnicity, educational attainment,

TABLE 2 Descriptive characteristics of POUNDS Lost participants with overweight and obesity from a subset with 24-h recall data by 6-mo changes in healthful dietary variety tertile (n = 356)[1]

	T1 (n = 118)	T2 (n = 119)	T3 (n = 119)	P value	P-trend
Age, y	52.3 ± 0.82	52.6 ± 0.81	52.0 ± 0.81	0.87	0.78
Sex, % female	60.2	48.7	55.5	0.21	—
Race/ethnicity, % white	87.3	87.4	79.0	0.12	—
Education, % ≥college degree	71.2	76.5	65.6	0.18	—
Annual household income, % ≥$100,000	37.3	32.7	32.8	0.70	—
US Healthy Food Diversity Score, Δ/6 mo	−0.09 ± 0.003[c]	−0.01 ± 0.003[b]	0.06 ± 0.003[a]	<0.0001	<0.0001
Baseline physical activity score[2]	7.01 ± 0.13	7.10 ± 0.13	6.87 ± 0.13	0.45	0.46
Smoker, % ever smoker	47.5	42.9	35.3	0.16	—
Weight, kg	93.9 ± 1.48	94.5 ± 1.47	94.1 ± 1.47	0.96	0.88
Δ Weight, kg/6 mo	−6.67 ± 0.52[a,b]	−6.30 ± 0.52[a]	−8.15 ± 0.52[b]	0.03	0.05
Waist circumference, cm	105 ± 1.22	104 ± 1.21	105 ± 1.21	0.86	0.97
Δ Waist circumference, cm/6 mo	−7.10 ± 0.58[a,b]	−6.11 ± 0.57[a]	−8.64 ± 0.57[b]	0.008	0.08
Total body fat,[3] %	37.4 ± 0.63	36.3 ± 0.63	37.1 ± 0.63	0.43	0.69
Δ Body fat, %/6 mo	−2.88 ± 0.28	−2.78 ± 0.28	−3.39 ± 0.27	0.24	0.20
Trunk fat,[3] %	38.4 ± 0.55	37.3 ± 0.55	37.9 ± 0.55	0.35	0.52
Δ Trunk fat, %/6 mo	−3.57 ± 0.37	−3.50 ± 0.37	−4.39 ± 0.37	0.16	0.12

[1] Data are presented as means ± SEs or percentages. From the 367 participants with dietary data at baseline, 356 had data at 6 mo. Only 186 had data at 2 y, and thus variety scores at 2 y were not computed. Changes in dietary variety were categorized into the following tertiles: T1 (−0.21 to −0.05), T2 (−0.04 to 0.01), and T3 (0.01–0.17). Tukey adjustment was used for all post-hoc comparisons between individuals in T1, T2, and T3. Labeled means in a row without a common superscript letter differ. POUNDS Lost, Preventing Overweight Using Novel Dietary Strategies; T1, reduced dietary variety; T2, stable dietary variety; T3, increased dietary variety.

[2] Habitual physical activity was assessed by use of the validated 16-item Baecke physical activity questionnaire (21), and total physical activity was calculated by summing the leisure, sports, and work activity indexes.

[3] Percentages of body fat and trunk fat were measured by use of DXA.

household income, 6-mo change in physical activity, 6-mo adherence to energy goals, and corresponding baseline indicator.

We used mixed linear models with maximum likelihood estimation and an unstructured covariance matrix to examine the association between tertile of change in variety score between baseline and 6 mo and changes in adiposity indicators over 2 y, adjusting for the same covariates. Tukey adjustment was used for all post-hoc comparisons between individuals in T1, T2, or T3. We also descriptively examined changes in food group intake within each variety tertile.

We tested for effect modification between the US Healthy Food Diversity index and diet arm, sex, race/ethnicity, age, and educational attainment using an a priori $p < 0.05$ to establish significance. All analyses were conducted during 2015 by use of SAS version 9.4.

Results

Descriptive characteristics. Descriptive characteristics of the sample are presented in **Tables 1** and **2**. The sample was predominately comprised of white (84%) and female (56%) participants, and mean age was 52 y. Most participants had higher education (72% with college degree or more), and 34% had household incomes ≥$100K. Self-reported physical activity was relatively stable over the 2-y period. In the first 6 mo, participants lost a mean of 6.9 kg of weight and 7.1 cm of WC. By 2-y, the typical participant regained 2.6 kg from their maximum weight loss at 6 mo and 1.6 cm from their maximum reduction in WC. Patterns of reduction and regain for percentages of body and trunk fat were similar. Demographic characteristics, physical activity, and smoking status did not differ by 6-mo changes in the healthy dietary variety tertile. Both body weight and waist circumference reduction were greater in the group in T3 than in the group in T2.

No significant interactions between changes in the US Healthy Food Diversity index with sex, race/ethnicity, age, or educational attainment were detected (data not shown). Because the interaction with the diet arm was also not significant (p-interaction = 0.41), treatment groups were combined, and the diet arm was adjusted for in all analyses.

6-mo and 2-y associations between changes in variety, weight, and adiposity. We examined whether continuous changes in the variety index predicted changes in weight and other adiposity indicators (**Table 3**). There was a significant positive association between the variety index and total energy intake (β = 1084, P = 0.04) (i.e., an ~100-kcal increase in energy intake/d for a 0.1-unit increase in the variety score). Energy prescriptions at 6 mo were not correlated with the variety index, although positive departures from energy prescriptions inversely correlated with the variety index at baseline and 6 mo (data not shown). At both 6 mo and 2 y, there were concomitant reductions in weight, WC, total body fat percentage, and trunk fat percentage as dietary variety increased in all models.

We also examined whether the group in T3 had greater reductions in body weight and other adiposity parameters at 6-mo than the groups in T2 or T1. Energy departures from prescribed energy deficits were similar across tertiles of change in healthy dietary variety (data not shown). There was no difference in energy intake reduction across tertile of change in healthy food variety between baseline and 6 mo (−427 kcal/d (T1) compared with −260 kcal/d in T2 and T3, P = 0.12). However, reductions in body weight were greater in the group in T3 than in the groups in T2 or T1 [−8.6 kg in T3 compared with −6.7 kg in T2 (P = 0.02) compared with −7.0 kg in T1 (P = 0.059)] after adjusting for diet arm, lifestyle and demographic characteristics, changes in physical activity, adherence to energy goals, and baseline body weight. Similarly, reductions in WC were greater among participants on average in T3 than in T2 [−9.1 cm in T3 compared with −6.7 cm in T2 (P = 0.005) compared with −7.2 cm in T1 (P = 0.05)]. No differences in total percentage of body fat and trunk fat were observed, although on average the group in T3 lost marginally more trunk fat (P = 0.05) and body fat (P = 0.08) than the group in T2 (**Figure 1**).

The 2-y, multivariable-adjusted associations between healthy variety and adiposity were consistent with the 6-mo findings (**Figure 2**) but were more robust. The group in T3 lost more weight at 2 y (−4.0 kg) than the groups in T2 (−1.8 kg, P = 0.02) or T1 (−1.8 kg, P = 0.02). T3 was also associated with greater reductions in WC (−5.43 cm) compared with T2 (−3.0 cm, P = 0.01) or T1 (−2.9 cm, P = 0.01). On average, both percentages of body fat and trunk fat were reduced among individuals in T3 compared with T2. Body fat was reduced by 0.91% in T3, whereas it increased by 0.16% in T2 (P = 0.02). Similarly, trunk fat was reduced by 1.0% in the group in T3, whereas it increased by 0.38% in the group in T2 (P = 0.02). Income slightly attenuated the results in all models. No significant interactions between change in variety tertile and time were observed.

TABLE 3 Continuous associations between 6-mo changes in the US Healthy Food Diversity index and short-term and long-term changes in weight and adiposity among POUNDS Lost participants with overweight and obesity (n = 356)[1]

	6 mo		2 y	
	Δ	*P* value	Δ	*P* value
Δ Energy intake, kcal/d				
Model 1[2]	903 ± 518	0.08	—	
Model 2[3]	1084 ± 525	0.04	—	
Δ Weight, kg				
Model 1[2]	−7.85 ± 4.18	0.06	−16.7 ± 5.57	0.003
Model 2[3]	−8.50 ± 4.28	0.048	−17.5 ± 5.77	0.003
Model 3[4]	−9.79 ± 4.18	0.02	−18.4 ± 5.68	0.001
Δ Waist circumference, cm				
Model 1[2]	−7.57 ± 4.69	0.11	−16.5 ± 6.12	0.007
Model 2[3]	−8.67 ± 4.76	0.07	−18.6 ± 6.23	0.003
Model 3[4]	−10.3 ± 4.59	0.03	−20.1 ± 6.03	0.001
Δ DXA total body fat, %				
Model 1[2]	−3.24 ± 2.23	0.15	−6.37 ± 2.97	00.03
Model 2[3]	−4.59 ± 2.19	0.04	−7.76 ± 3.03	0.01
Model 3[4]	−4.61 ± 2.20	0.04	−7.77 ± 3.03	0.01
Δ DXA trunk fat, %				
Model 1[2]	−4.92 ± 2.99	0.10	−8.11 ± 3.83	0.03
Model 2[3]	−6.66 ± 2.95	0.02	−9.79 ± 3.92	0.01
Model 3[4]	−6.65 ± 2.95	0.03	−9.78 ± 3.92	0.01

[1] Data are presented as adjusted β values ± SEs for continuous models. POUNDS Lost, Preventing Overweight Using Novel Dietary Strategies.

[2] Adjusted for age, sex, and diet arm for 6-mo changes; adjusted for age, sex, time, interaction between the variety index and time, and diet arm for 2-y changes.

[3] Adjusted for model 1 covariates + smoking (current and ever smoker compared with nonsmoker), race/ethnicity (white compared with nonwhite), educational attainment (college graduate compared with some college or high school graduate), household income [low (<$50,000), medium ($50,000–100,000), and high income (>$100,000)], change in physical activity score (0–6 mo), and adherence to energy goals at 6 mo.

[4] Adjusted for model 2 covariates + corresponding baseline adiposity indicator (i.e., body weight, waist circumference, total percentage of body fat, or total percentage of trunk fat).

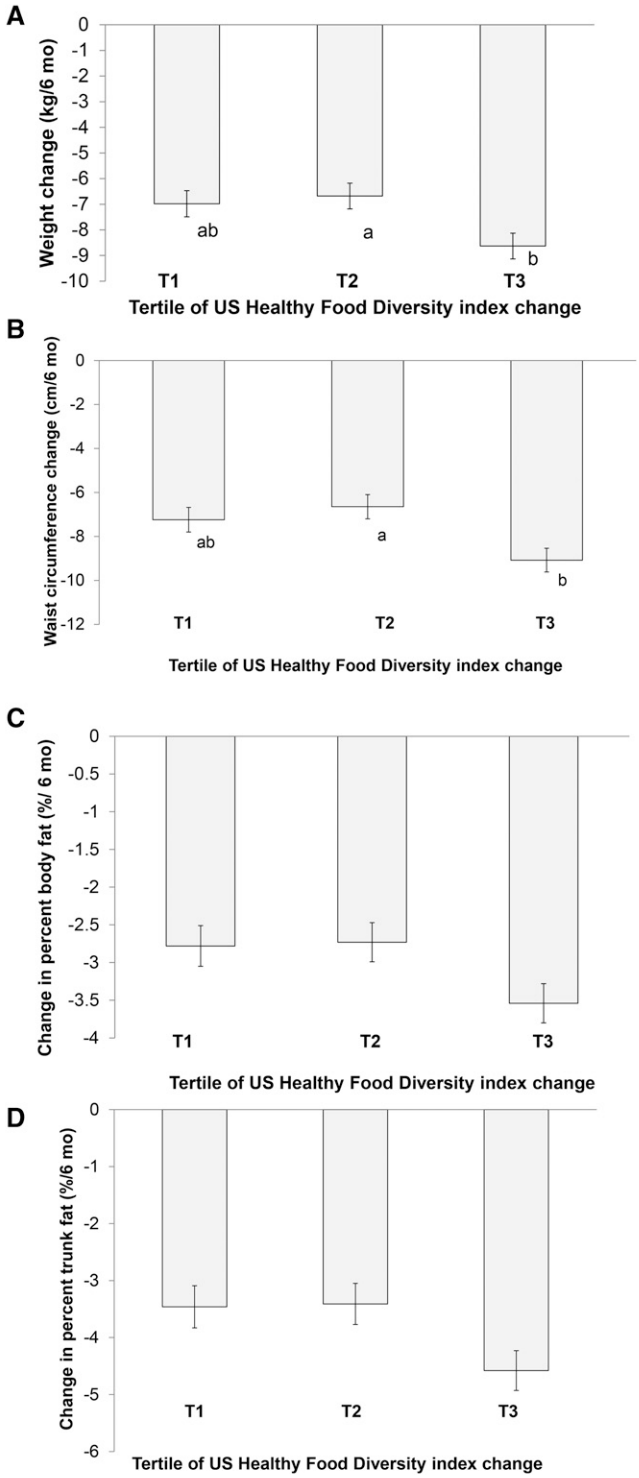

FIGURE 1 Mean differences in body weight (A), waist circumference (B), percentage of body fat (C), and percentage of trunk fat (D) from baseline to 6 mo by tertiles of 6-mo changes in the US Healthy Food Diversity index among POUNDS Lost participants with overweight and obesity. Data are presented as adjusted means with standard errors. Mean changes are adjusted for age, sex, diet arm, smoking (current or ever smoker compared with nonsmoker), race/ethnicity (white compared with nonwhite), educational attainment (college graduate compared with some college or high school graduate), household income [low (<\$50,000), medium (\$50,000–100,000), or high income (>\$100,000)], change in physical activity score (0–6 mo), adherence to energy goals at 6 mo, and corresponding baseline adiposity indicator (i.e., body weight, waist circumference, total percentage of body fat, or total percentage of trunk fat). Changes in dietary variety were categorized into the following tertiles: T1 (−0.21 to −0.05), T2 (−0.04 to 0.01), and T3 (0.01–0.17). Tukey adjustment was used for all post-hoc comparisons between T1, T2, and T3. The value next to each bar represents the change in adiposity parameter for the corresponding tertile. Labeled means without a common letter differ. There are ~119 participants in each tertile. POUNDS Lost, Preventing Overweight Using Novel Dietary Strategies; T1, reduced dietary variety; T2, stable dietary variety; T3, increased dietary variety.

Differences in food group intake among variety change tertiles. The descriptive differences in food intake patterns within each tertile are detailed in **Supplemental Tables 1–3**. The group in T3 significantly increased their intake of whole grains, citrus, melon and berries, other fruits, dark green vegetables, orange vegetables, low-fat milk, and yogurt. Simultaneously, they reduced their intake of refined grains, lean meats, added sugars, and discretionary fats. Similar decreases were observed among participants in the other 2 tertiles. Additionally, the group in T3 maintained both the total number of foods consumed per day and daily food volume, whereas the groups in T1 and T2 either reduced or maintained the total number of foods consumed per day and generally reduced their daily food volume ($P < 0.0001$ for T1, $P = 0.07$ for T2). Participants in both T1 and T2, on average, generally maintained or decreased the intake of healthful food groups, including whole grains, low-fat milk, and citrus fruit, melon and berries, but increased their intake of poultry.

Discussion

This study showed that increasing dietary variety within healthful foods during a 2-y weight-loss trial is associated with significantly greater short- and long-term weight loss and reduction in WC, total percentages of body fat, and trunk fat compared with maintaining or reducing variety. Associations between dietary variety and weight were present at both 6 mo and 2 y, but the associations were stronger at 2 y, suggesting that dietary variety may facilitate both short- and long-term weight loss maintenance.

Higher initial weight loss has been shown to facilitate long-term weight loss maintenance in the literature (6), which may partly explain the 2-y results. Because dietary adherence and sustained energy restriction more strongly predict weight loss than macronutrient composition (6), increasing food variety may have helped participants adhere to their prescribed diet by expanding the number of healthful, lower-calorie options available.

Notably, the group in T3 had less reduction in energy intake than participants in the other tertiles despite losing more weight. This finding was not explained by observing higher energy prescriptions among those who increased their food variety. However, energy departures from the prescribed energy intake were significantly and inversely associated with the variety index at baseline and 6 mo (data not shown). Thus, individuals who adhered more to their energy prescriptions generally had higher variety scores, suggesting that greater food variety may have improved the sustainability of reduced-calorie dietary patterns. Similarly, underreporting may have been greater in the other tertiles, particularly given the correlation between underreporting and higher body weight (20). Finally, the reduction in body weight and other adiposity parameters may have partly been

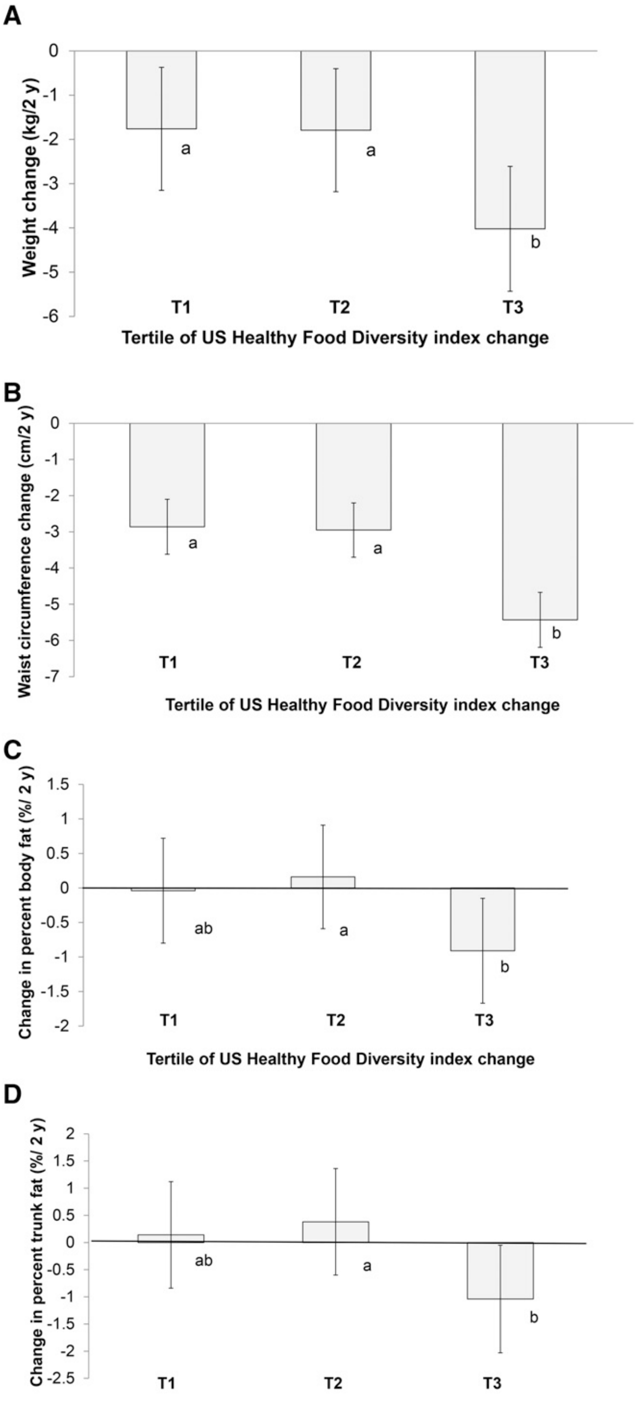

FIGURE 2 Repeated-measures mean differences in body weight (A), waist circumference (B), percentage of body fat (C), and percentage of trunk fat (D) from baseline to 2 y by tertiles of 6-mo changes in the US Healthy Food Diversity index among POUNDS Lost participants with overweight and obesity. Data are presented as adjusted means with standard errors. Mean changes are adjusted for age, sex, diet arm, time, the interaction between the variety index and time, smoking (current or ever smoker compared with nonsmoker), race (white compared with nonwhite), educational attainment (college graduate compared with some college or high school graduate), household income [low (<\$50,000), medium (\$50,000–100,000), or high income (>\$100,000)], change in physical activity score (0–6 mo), adherence to energy goals at 6 mo, and baseline adiposity indicator (i.e., body weight, waist circumference, total percentage of body fat, or total percentage of trunk fat). Changes in dietary variety were categorized into the following tertiles: T1 (−0.21 to −0.05), T2 (−0.04 to 0.01), and T3 (0.01–0.17). Tukey adjustment was used for all post-hoc comparisons between T1, T2, and T3. The value next to each bar represents the change in adiposity parameter for the corresponding tertile. Labeled means without a common letter differ. There are ~119 participants in each tertile. POUNDS Lost, Preventing Overweight Using Novel Dietary Strategies; T1, reduced dietary variety; T2, stable dietary variety; T3, increased dietary variety.

driven by other metabolic changes (16), improved satiety (13, 22, 23), or potential alterations in the gut microbiome (24).

Because the food variety index used in this study simultaneously captures dietary variety, quality, and proportionality, we can only infer some of the dietary changes that participants made in order to develop more concrete food-based recommendations. For example, the group in T3 lost the most weight and maintained their total food variety and food volume by shifting intake to healthier, lower energy-dense food groups including fruits, whole grains, and low-fat dairy, supporting the hypothesis that greater variety within low energy-dense plant-based food patterns can facilitate successful weight loss and maintenance (25).

There is some evidence from observational studies that greater food variety is associated with lower odds of obesity, elevated WC, and body fatness. Azadbakht and Esmaillzadeh (26) and Azadbakht et al. (27) observed lower rates of obesity among Tehranian adults in the highest compared with lowest quintile of a dietary diversity score. Additionally, we previously found that individuals with greater healthful dietary variety had lower odds of overweight, obesity, and other markers of body fatness in a cross-sectional, nationally representative US cohort (15). However, most research examining the role of dietary variety in body weight regulation has focused on the role of reducing variety to decrease food intake (11, 28, 29). Although many of these studies have observed reductions in variety and energy intake during the intervention, these changes have not been strongly associated with weight loss (28). Consistent with the present analysis, one study among weight-loss participants observed that decreased variety within high-fat foods and increased variety within low-fat breads improved weight loss (30). Although this finding was promising, the variety measure did not account for serving size, only considered a limited number of foods, and did not assess variability in dietary quality. Such limitations may have biased risk estimates by increasing measurement error and by insufficiently distinguishing between individuals who consume highly varied compared with minimally varied diets (31). Our study used a construct for dietary variety that lessened those limitations, and thus, it enhanced methodological accuracy and the potential for translation of this work toward public health and clinical recommendations.

Evidence from the present study suggests that increasing healthful dietary variety is a promising approach to promote weight loss, weight loss maintenance, and adiposity reduction. Moreover, although the pathways driving these associations require further investigation, this study suggests a number of plausible mechanisms. Diets in the present study with more variation were associated with a higher intake of plant-based foods, which are more physiologically satiating and could promote dietary adherence by reducing barriers such as hunger (13). Additionally, greater healthful dietary variety may ameliorate feelings of deprivation and improve diet satisfaction, which are important correlates of long-term weight maintenance (32). Previous studies demonstrate that greater dietary variety can attenuate the decline in enjoyment associated with monotonous eating (10, 33). Promoting healthful variety to make reduced-energy dietary patterns more gratifying and less restrictive may temper food cravings typical of weight maintenance regimens (32). Finally, increasing variety in some domains may mitigate the decline in enjoyment that concur with reducing the variety and intake of food groups that must be restricted for successful weight loss (32).

To our knowledge, our study is one of the first longitudinal studies to examine the role of changes in dietary variety on weight loss and weight maintenance, and supports preliminary evidence from cross-sectional studies. We used an accurate and validated measurement of dietary variety that considered the healthfulness and consumption amount of each food (14). By use of multiple food records and dietary recalls rather than FFQs, it was possible to get a precise estimate of usual dietary variety among individuals who may have distinct food patterns. All outcome measures were precisely measured at multiple time points, and the 2-y study duration provides important insight into factors that may help with both weight loss and prolonged weight loss maintenance.

Some limitations of the present analysis must be noted. The predominately white study population lessened generalizability to other racial/ethnic groups. Additionally, it was not possible to estimate healthy variety scores at 2 y because of limited sample size. Given that some weight regain was observed during the maintenance phase, variety scores may have decreased for some individuals. Although our results at 2 y are robust when using short-term changes in variety as predictor, it would be worth exploring the role of prolonged dietary changes in further weight-loss trials. Participants may have experienced different constraints on their food choices or have selected a wider variety of less healthful foods, which may have influenced their variety scores and weight outcomes. However, variety scores at 6 mo were similar among all diet arms excluding the high-fat, high-protein diet arm (data not shown), and we adjusted for diet arm as a potential confounding variable. Finally, participants were not advised about reducing or increasing their variety within certain food groups, so there may be other characteristics about the group that successfully increased their healthful dietary variety and lost weight that differed from participants in the other groups that we were unable to ascertain. However, given the consistency of association with previous findings and biological plausibility, such residual confounding is unlikely to change the conclusions.

Given the high rates of weight loss attrition and weight regain among individuals attempting to lose weight, it is important to consider strategies that accentuate the benefits of lifelong, sustainable dietary changes. Our study supports improving healthful dietary variety as a behavioral tool with the potential to encourage long-term weight loss and maintenance. Future research is needed to confirm whether increasing variety in healthful foods and decreasing variety in less healthful foods makes weight loss and weight maintenance less challenging and more successful.

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